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Minireview

Do You See What I'm Saying? Interactions between Auditory and Visual Cortices in Cochlear Implant Users

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Primary sensory cortices are generally thought to be devoted to one sensory modality—vision, hearing, or touch, for example. Surprising interactions between these sensory modes have recently been reported. One example demonstrates that people with cochlear implants show increased activity in visual cortex when listening to speech; this may be related to enhanced lipreading ability.

A currently hot debate in neuroscience concerns the functional role of unimodal sensory cortex. The conventional interpretation had long held that each modality has its sensory receiving area in the cortex, exclusively devoted to processing sensory information from one set of sense organs. Although in many respects this view is probably still correct, recent years have yielded sometimes surprising data suggesting that interactions across "unimodal" cortices may be more widespread than previously suspected.

This cross-modal phenomenon has been demonstrated in a variety of different circumstances in which sensory deprivation induces functional reorganization. For example, in hemodynamic or electromagnetic studies with blind individuals, activity in occipital cortical regions has been observed when acoustic or tactile information must be processed (Kujala et al., 2000). Moreover, these areas appear to play a significant functional role, since transcranial magnetic stimulation of occipital cortex induces behavioral disruption in Braille pattern processing tasks (Hamilton and Pascual-Leone, 1998). Similarly, congenitally deaf individuals show activity in areas that are classically thought of as unimodal auditory cortex when processing certain types of visual information, including sign language stimuli (Petitto et al., 2000). The idea of cross-talk between sensory regions has been given added impetus by studies of cross-modal plasticity in animals (Rauschecker, 1995), which demonstrate that neurons that normally would have a visual function are taken over by auditory and somatosensory inputs in binocularly deprived cats. Moreover, it is now also known that the auditory cortex can take on functional properties of visual neurons when it is "rewired" to receive input from the eye (Sur and Leamey, 2001).

Giraud and colleagues present data in the previous issue of *Neuron* (Giraud et al., 2001) that speak to the issue of sensory cross-talk in the case of people suffering from profound hearing loss who have learned to use cochlear implants to understand speech. This population provides an interesting opportunity to examine how cortical responses change as a function of time when sensory stimulation is provided via the implant device. The subjects in question had all lost hearing as adults and were therefore excellent clinical candidates for reestablishing speech comprehension via the implant; indeed, their performance on speech tasks reached upward of 90% after wearing the devices for 2–4 years.

The investigators used positron emission tomography at intervals over 3 years to measure brain activation, while subjects were stimulated with words or various noise control conditions. Several regions of auditory cortex were found to be increasingly more active as a function of time using the implant, which is not surprising, since it likely reflects the cortical activity associated with decoding speech sounds, which improves over time. What is more remarkable is that there was also a concomitant increase in visual cortical activity. This change was shown by the authors to be relatively specific, as it was primarily elicited by speech and other meaningful sounds but not by noise. Thus, contrary to what conventional wisdom might have predicted, visual activity increased rather than decreased when auditory input was available via the implant. The explanation offered by the authors is a good one: they propose that the visual cortex participates in speech decoding in these people because they have learned to use lipreading along with auditory information to understand speech. Since the cochlear implant provides a degraded input to the auditory system, as compared to what the cochlea would normally provide, implant users rely on lipreading to help disambiguate speech in conversational settings. The most convincing evidence that lipreading underlies the observed visual cortex response comes from the authors' demonstration that lipreading ability, as measured independently, correlates highly with visual cortex activation by speech.

The interaction between visual and auditory information in processing speech has long been familiar to psychologists from the McGurk effect (McGurk and MacDonald, 1976), which occurs when conflicting speech and visual (lipreading) information is presented. Under these conditions, speech is often misperceived, showing that it can be influenced by visual input. It has also been shown that viewing silent videos of people mouthing words is sufficient to activate the auditory cortex in normal hearing individuals (Calvert et al., 1997). These examples of normally occurring cross-modal interaction help to understand the phenomenon described by Giraud et al. However, under most circumstances, activity in visual cortex is not associated with listening to speech, nor do lesions in visual cortex in any way degrade speech perception. What is of interest in the present findings, therefore, is the possibility that some sort of obligatory cross-modal association has been formed in the implant users. As Giraud et al. put it: "Our data point to the importance of progressive refinements in audio-visual coupling as the probable substrate of long-term functional improvement in speech discrimination."

This conclusion provides interesting testable hypoth-

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eses for further research, which should help to clarify the plastic processes underlying the learning that implant users undergo, as well as the nature of cross-modal interactions more generally. With respect to this latter point, it is important to note that such cross-modal processes may also exist in normal cognition, though they are far from being understood. Functional imaging studies have reported conflicting evidence concerning the functional relationships of modality-specific areas during perceptual processing. For example, some studies have found that cortical activity decreases in visual cortices when performing a demanding auditory task and, similarly, that visual tasks induce suppression of auditory cortical activity (e.g., Paus et al., 1997; Haxby et al., 1994; for review, see Zatorre and Binder, 2000). However, activity in the areas specialized for the nonstimulated modality can sometimes show increases, such as when a musical stimulus elicits increased blood flow in secondary visual cortical areas (e.g., Zatorre et al., 1994). Hence, there may be cross-modal interactions of a complex nature associated with normal perceptual processing, and the extent to which these processes form part of the picture revealed by the Giraud et al. study remains to be seen.

Another critical question is the degree to which the visual processing observed in the implant users reflects a necessary neural operation relevant to speech comprehension. An alternative interpretation, equally consistent with the data presented, might be that visual activation is elicited by speech as a side effect of the close association between speech and lipreading, even though it is not essential to the task of speech decoding. This interpretation is feasible, given that the implant users actually achieve good speech comprehension even when lip reading is not possible. One way to examine this question might be via techniques such as transcranial magnetic stimulation, which provides noninvasive temporary disruption of neural processes in order to establish their contribution to a given task (Hamilton and Pascual-Leone, 1998).

A further question that is raised by these data is whether cross-modal activation represents a form of mental imagery. Several studies have shown that visual or auditory cortices may be recruited in normal subjects in the absence of any stimulus when performing certain imagery tasks. For example, when people are asked to imagine a visual scene with their eyes closed, visual cortical areas increase their activity (Kosslyn et al., 1999). Similarly, when people are asked to hum a tune in their head in silence, activation is seen in auditory cortex (Zatorre et al., 1996). Thus, the act of mentally recreating a sensory event seems to entail the recruitment of the relevant sensory cortices, presumably because the phenomenological experience of imagery is tied to sensory-specific neural activity patterns. Do implant users use these preexisting mechanisms when processing speech and, hence, engage visual regions because of visual imagery of lipreading, or is there a fundamentally different associative learning mechanism that develops? And how would one characterize the difference between associative learning and imagery—might they rely on essentially the same underlying mechanism?

An additional issue that should be mentioned in this context concerns how age affects the degree of cross-modal plasticity that may be elicited. Contrary to conventional assumptions, quite a lot of recent data, including the findings of Giraud et al., indicate that significant changes may occur in the adult nervous system in response to new learning. However, the effect of age is certainly important in many types of processes that entail reorganization and often imposes limits on the type or degree of change that may occur. It will be interesting to see, for instance, whether prelingually deaf children who use cochlear implants will show a similar pattern of cross-modal interaction as demonstrated for adults.

The findings of Giraud et al. are thus valuable in two ways. First, they provide important information concerning the neural basis by which cochlear implants may work, thereby helping us to think about ways to continue their refinement and perhaps even to push forward work on sensory substitution devices in other domains, such as auditory prostheses to be used by the blind. Second, they raise a variety of basic questions about the functional properties of sensory cortices. These questions, which until recently had not really been asked, are important in moving beyond simple models of cerebral organization toward a more nuanced view of how sensory systems interact in both the normal brain and in a nervous system that has had to adapt to sensory loss or damage.

Selected Reading

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